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December 27, 1962

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Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.

Attention: RRMA-231

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Via: Inspector of Naval Material
10 North 8th Street
Reading, Pennsylvania

Subject: ULTRASONIC WELDING OF REFRACTORY METALS
Progress Report No. 10
For the Period 1 August through 30 September, 1962
Navy Contract No. NOw-61-0410-c

Gentlemen:

During this extension report period, attention was given to ultrasonic welding of Mo-0.5Ti alloy.

Reemphasis was placed on investigations into the weldability of this material because of priorities agreed upon at a Bureau of Naval Weapons conference on March 2, 1962. This discussion also indicated that the alloy's technology was relatively well explored, its availability good and subject to improvement through the current DOD Refractory Metals Sheet Rolling Program.

Although our prior study had shown that Mo-0.5Ti demonstrated metallurgical characteristics conducive to good ultrasonic welding, the material had also shown a tendency to crack under some circumstances.

As had been done in a previous report covering D-31*, an extensive literature study concerning this alloy was instituted, and this action was coupled with direct inquiries to persons and companies known to have appropriate experience. (Available Russian literature on ultrasonic welding was also helpful.) In addition, our former work with Mo-0.5Ti was reanalyzed. This review was undertaken in an attempt to isolate and resolve problems pertaining to the propensity of the alloy to crack under certain conditions of ultrasonic welding.

Based on the above, a new series of studies was planned, executed, and the results analysed.

* Progress Report No. 9

Similar to the determinations for D-31 alloy, indications are that the quality of refractory metals in general, and their contamination in particular, may well be the major controlling factors contributing to difficulties encountered in the ultrasonic welding of this alloy.

Some of the data contained in this report, as with D-31 alloy, has been partially deduced from work performed for the United States Air Force.*

TENSILE-SHEAR DATA

Table I summarizes tensile-shear strength data of ultrasonically welded Mo-0.5Ti material during this period. As shown in the table, the studies dealt with materials procured in 1961 ("old"), and in 1962 ("new"). As may be noted, "old" 0.0055-inch material produced erratic results (see Studies Nos. 1, 2). By contrast, the performance of "new" 0.010-inch stock was considerably better, but can not yet be regarded as altogether satisfactory. (See Studies Nos. 3, 4).

No tensile-shear strength data could be determined with "old" 0.008-inch stock. Efforts were made to establish welding parameters statistically, but of the 43 specimens with which welding was attempted, only 13 produced bonds with tensile-shear strength ranging from 15 to 103 pounds. The remainder either did not weld at all, or cracked during welding.

METALLOGRAPHIC STUDIES

General Observations

Specimens from Study Nos. 1 and 2 were metallographically analysed, and the results were as follows:

Study No.	Sonotrode Tip Radii, inch	Direction of Sectioning (1)	Number of Specimens: Used	Examined	Broken During Sectioning
1	0.25	Longitudinal	25	14	11
		Transverse	25	14	11
2	0.5	Longitudinal	25	5	20
		Transverse	25	4	21

(1) To the direction of tip displacement

* Development of Ultrasonic Welding Equipment for Refractory Metals. Contract AF 33(600)-43026. ASD Project No. 7-888, Fabrication Branch, Manufacturing Technology Laboratory, AFSC Aeronautical Systems Div., United States Air Force.

The above study and Figure 1 depict the reasons for the inconsistent and low tensile-shear strength values obtained in Study No. 2 using "old" 0.005-inch Mo-0.5Ti alloy foil. Cracks usually started at the weld interface, following the periphery of the local bond (Figure 2).

As noted above, considerably better results were obtained in tensile-shear strength consistency of ultrasonically spot-welded "new" 0.010-inch material. Twenty-nine of the welded specimens from Study No. 3 were examined metallographically, with the results as tabulated below:

Study No.	Direction of Sectioning (1)	Number of Specimens Examined	Results, (2) Good Bond, No Crack	Good Partial Bond	No Bond	Good Bond, One Crack
3	Longitudinal	14	1	3	8	2
	Transverse	15	2	4	9	4

(1) To the direction of tip displacement
(2) Along particular sections

Figures 3 and 4 exhibit an excellent metallurgical bond in Mo-0.5Ti alloy. Figure 3 illustrates a cross section along a very good partial bond with local turbulent interpenetration, and no evidence of cracking whatever. Figure 4, a detail from Figure 3 under higher magnification, also emphasizes the turbulent interpenetration, reaching 25 percent of the sheet gage. The heavy mutual interpenetration suggests that under certain circumstances, possibly relating to ultrasonic plasticity and/or local heat, the weld interface possesses a high degree of ductility. Cracking in the 0.010-inch specimens was far less pronounced than in the 0.005-inch coupons, and cracks which did result were microcracks, and not gross uncontrolled cracks as in 0.0055-inch material (Study No. 2).

The photomicrographs of Figures 3 and 4 were taken from Study No. 3. Study No. 4 should produce even better metallographic results, because of higher and more constant tensile-shear strength.

Cracking Pattern

In contrast to the character of cracks in 0.0055-inch material, microcracks of the 0.010-inch alloy are concentrated on the weld interface (Figures 5 and 6). Figure 5 shows the heaviest microcrack observed from the 29 specimens examined metallographically during Study No. 3, while Figure 6 represents a typical microcrack. In no instance did microcracks extend to the surface, a fact also substantiated by inspection of a number of welded 0.010-inch Mo-0.5Ti specimens by means of a highly sensitive

penetrant (SUPER PENTREX, Magnaflux Corporation), and reported in prior study*. The planar sectioning for metallographic investigation has also been reported previously**.

On the basis of these limited studies, it is not yet possible to draw definitive conclusions regarding the occurrence or preponderance of the cracks in this material with relation to the weld envelope or the tip displacement. Additional studies are necessary.

INTERFACE STUDIES

Interfaces of specimens were studied under the binocular microscope subsequent to fracture in tensile-shear testing. A résumé of these observations is given below. (Detailed descriptions of interfaces, appropriate photographs, and results of the literature studies will be included in the final report as part of the general analysis of the investigations).

In general, when ultrasonically welded, Mo-0.5Ti does not seem to behave in a manner similar to other metals and alloys.

Sonotrode-Work Interface

There are two coupling areas within the contact envelope, one on its periphery, and the other internal. Usually, each consists of several streaks elongated in the direction of the tip displacement. The peripheral coupling area is considerably smaller than the weld interface markings, and both seem to be arrested in their growth. Very little heat discoloration exists, but this appears to increase with greater tip radius and with higher welding power.

Weld Interface

There are bond areas, located on a shiny background. These bond areas appear to replicate the sonotrode-work interface coupling pattern. No heat discoloration is present, but fretting-like debris has been observed on some weld interfaces.

Anvil-Work Interface

Unlike others, the anvil-work interface shows coupling mainly on the envelope periphery, with little evidence of coupling observable inside the envelope. Heavy discoloration is present outside the envelope, suggesting an elevated temperature. This discoloration increased as welding power increased, and decreased on specimens which cracked during the welding process, suggesting decoupling and reduced energy delivery.

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* Progress Report No. 5
** Progress Report No. 4

TENTATIVE CONCLUSIONS

1. Mo-0.5Ti

On the basis of these limited studies, there are some provisional conclusions which may be drawn regarding the ultrasonic welding of Mo-0.5Ti alloy material.

a. The material seems to have excellent metallurgical susceptibility to ultrasonic welding. In fact, it seems to show considerable interfacial ductility during ultrasonic welding. (Figures 3, 4).

b. Local partial bonds, formed initially on the weld interface, have a tendency to develop into bonds across the entire area of a given section of the weld envelope (Figure 3).

c. Thin material (0.0055 inch) procured in 1961 and designated "old", exhibited serious cracking (Figure 1) which appears to start at local partial bonds (Figure 2). The heavier material (0.010 inch) procured in 1962 and termed "new", has been found to be far less crack sensitive. Cracks which do form in this material are microcracks (Figures 5, 6).

d. Neither the occurrence nor the preponderance of cracks can at present be referenced either to position on the weld envelope or to the direction of the tip displacement.

e. Weld tensile-shear strength and consistency were poor in the "old" 0.0055-inch foil (Studies 1, 2, Table 1). Improvement developed with the increase of the sonotrode-tip radius and power (Study No. 2). A striking improvement in tensile-shear strength and consistency resulted with the use of "new" 0.010-inch Mo-0.5Ti alloy material (Studies 4, Table 1). It is not yet altogether clear why this improvement was achieved, but additional work now in progress is expected to shed more light on the problem.

f. The 0.75-inch spherical sonotrode-tip radius (75t) yielded better results (Study No. 4, Table 1) than did the 0.5-inch sonotrode-tip radius (50t) (Study No. 3, Table 1) with 0.010-inch alloy material.

Note: The metallurgical history of both the "new" 0.010-inch Mo-0.5Ti material and the "old" 0.0055-inch material is unknown. Hence, it is not yet possible to determine why the weldability of the former was so much better than the latter, although our prior experience had indicated a similar trend. It may be assumed currently that surface contamination has more over-all effect on the thinner material.

2. D-31* and Mo-0.5Ti Alloy Materials

a. Material quality in general, and its surface contamination in particular, seem to be the controlling factors in the initial unsuccessful welding of D-31, and in the tendency of Mo-0.5Ti to crack during ultrasonic welding.

b. It is imperative that future work with these and with other refractory metals (e.g. tungsten) be performed with alloys of the highest purity, and with full knowledge of their metallurgical history.

c. For future work, we should be able to procure the latest refractory metals produced under the DOD Refractory Metals Sheet Rolling Program, and should discuss directly with DOD Contractors the complete histories of metals used. To date, attempts to secure such information have been unsuccessful. Producers seem reluctant to reveal processing methods on the ground of proprietary rights.

Note: To expedite future activity, we have already moved to this end with the Bureau of Naval Weapons regarding D-31 alloys and tungsten. Similar action is planned with the Manufacturing Technology Laboratory, Aeronautical Systems Division, United States Air Force**, the monitoring agency for columbium, part of the DOD Refractory Metals Sheet Rolling Program.

FUTURE WORK

Future work covering the ultrasonic welding of Mo-0.5Ti alloy will concern itself with metallographic examination of contamination depth of used foil and sheet material recrystallized in some instances by this contractor and in others by Universal Cyclops Steel Corporation. Microhardness studies will also be undertaken.

It is anticipated that these investigations will permit the establishment of final conclusions.

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* Progress Report No. 9

** Telephone conversations: Mr. Hugh Black, ASD, Wright Field, and Mr. H. L. McKaig, Aeroprojects Incorporated, October 1, 1962.

Very truly yours,

Harold L. McKaig, Jr.

Harold L. McKaig, Jr.
Manager, Advance Projects

HLM:ss

Table I

SUMMARY OF TENSILE-SHEAR STRENGTH DATA OF ULTRASONICALLY WELDED MOLYBDENUM-0.5 TITANIUM ALLOY FOIL

Note: Tabs were degreased in acetone and abraded with No. 400 emery before welding

Study No.	Gage (inch)	Stock	Sonotrode Tip Radius, (inch)	Welding Parameters: Power, watts	Welding Parameters: Clamping Force, (pounds)	Welding Parameters: Time Interval, (second)	Tensile-Shear Data, lbs[1]: $\bar{x}$[2]	Tensile-Shear Data, lbs[1]: σ[3]	Tensile-Shear Data, lbs[1]: $\bar{x}-3\sigma$[4]	Tensile-Shear Data, lbs[1]: N[5]	Figure No.	Notes
1	0.0055	Old[6]	0.25	1100	400	0.5	26	18	-28	27		
2	0.0055	Old[6]	0.5	1400	700	0.5	48	23	-21	13	1,2	
3	0.010	New[7]	0.5	2900	1000	0.5	122	41	-1	23	3,4,5,6	
4	0.010	New[7]	0.75	3000	1000	0.5	179	24	107	21		
5	0.008	Old[6]	0.75	2400-3200	500-1000	0.3-0.5	-	-	-			See text

1) Statistically analyzed
2) $\bar{x}$ = Expected mean
3) σ = Standard deviation
4) $\bar{x} - 3\sigma$ = Expected minimum
5) N = Number of population
6) Material procured in 1961
7) Material procured in 1962

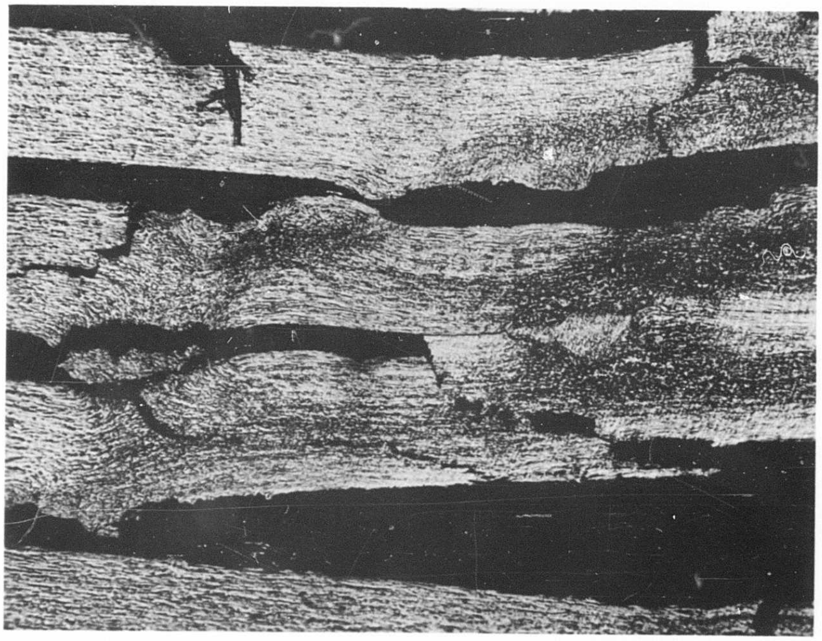

Figure 1

ULTRASONICALLY SPOTWELDED "OLD" 0.0055-INCH THICK
MOLYBDENUM-0.5 TITANIUM ALLOY SHEET
WITH 0.5-INCH SONOTRODE SPHERICAL-TIP RADIUS

Etchant: a. Sodium hydroxide 10%
b. Potassium ferric cyanide 10%

a. and b. mixed in the proportion 50:50

Magnification: 120X

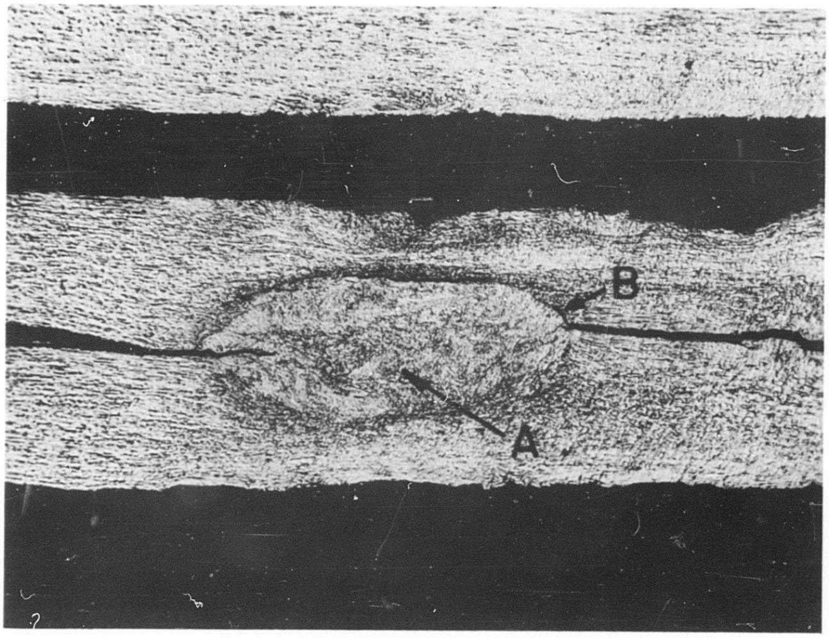

Figure 2

ULTRASONICALLY WELDED "OLD" 0.0055-INCH MOLYBDENUM-0.5 TITANIUM ALLOY FOIL SHOWING A LOCAL BOND "A" WITH A MICROCRACK "B" STARTING AT THE WELD INTERFACE AND FOLLOWING THE PERIPHERY OF THE LOCAL BOND

Etchant as in Figure 1

Magnification: 120X

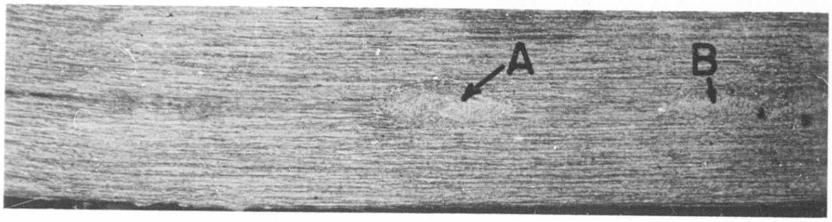

Figure 3

CROSS SECTION OF ULTRASONICALLY WELDED "NEW"
0.010-INCH MOLYBDENUM-0.5 TITANIUM ALLOY FOIL
SHOWING EXCELLENT BOND WITH HEAVY LOCAL INTERPENETRATION
(A and B)

Etchant as in Figure 1

Magnification: 50X

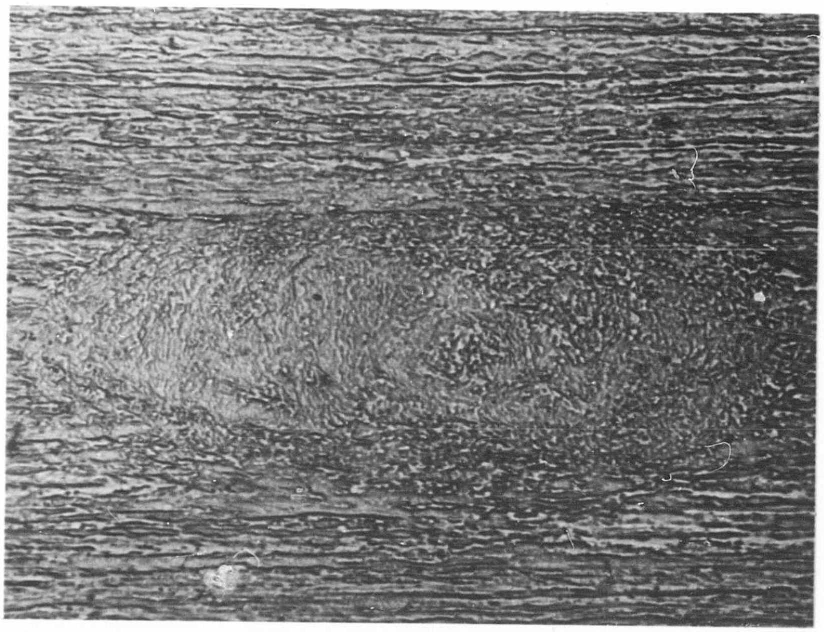

Figure 4

DETAIL <u>A</u> FROM FIGURE 3

Magnification: 300X

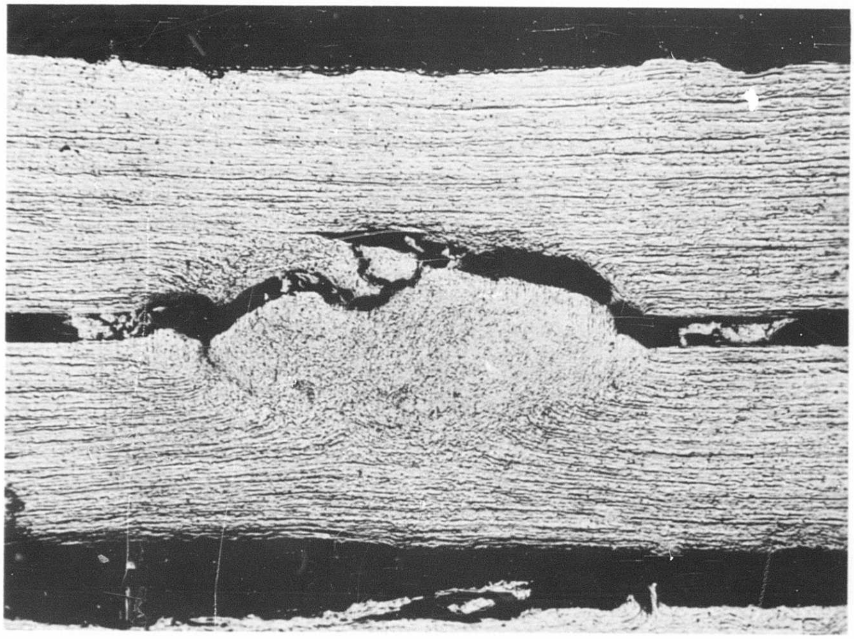

Figure 5

THE HEAVIEST-OBSERVED WELD INTERFACE MICROCRACK ON ULTRASONICALLY SPOTWELDED "NEW" 0.010-INCH MOLYBDENUM-0.5 TITANIUM FOIL. IT STARTS AT THE WELD INTERFACE AND FOLLOWS THE PERIPHERY OF THE LOCAL BOND. THE MICROCRACK DOES NOT EXTEND TO THE SURFACE.

Etchant as in Figure 1

Magnification: 120X

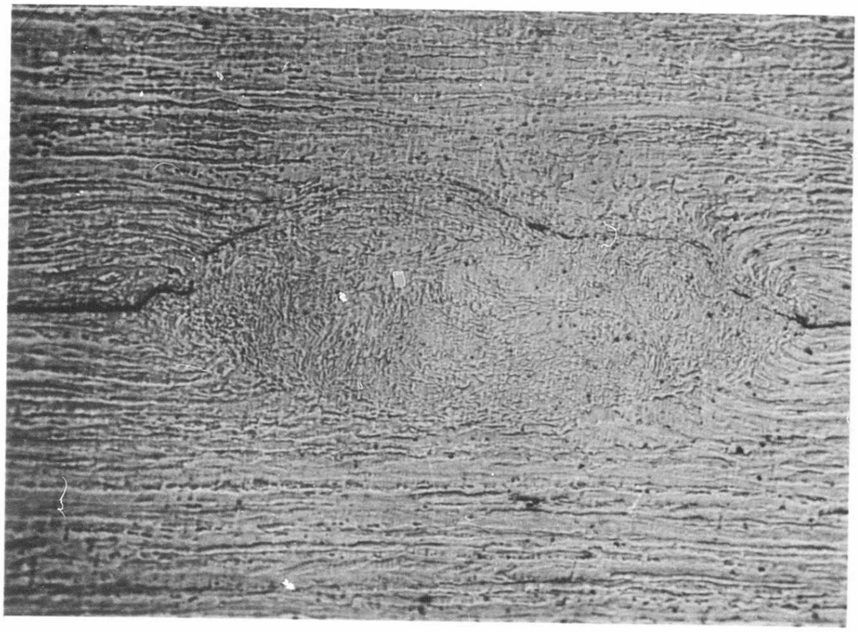

Figure 6

TYPICAL MICROCRACK ON ULTRASONICALLY WELDED "NEW"
0.010-INCH MOLYBDENUM-0.5 TITANIUM ALLOY FOIL
Etchant as in Figure 1
Magnification: 500X

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